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Performance and results of the RICH detector for kaon physics in Hall A at Jefferson Lab

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Abstract

A proximity focusing RICH detector has been constructed for the hadron High Resolution Spectrometer (HRS) of Jefferson Lab Experimental Hall-A. This detector is intended to provide excellent hadron identification up to a momentum of 2.5 GeV/c. The RICH uses a 15 mm thick liquid perfluorohexane radiator in proximity focusing geometry to produce Cherenkov photons traversing a 100 mm thick proximity gap filled with pure methane and converted into electrons by a thin film of CsI deposited on the cathode plane of a MWPC.

The detector has been successfully employed in the fixed target, high luminosity and high resolution hypernuclear spectroscopy experiment. With its use as a kaon identifier in the 2 GeV/c region, the very large contribution from pions and protons to the hypernuclear spectrum was reduced to a negligible level. The basic parameters and the resulting performance obtained during the experiment are reported in this paper.

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Keywords: RICH; Particle identification; Kaon identification; Cherenkov detector

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1. Introduction

A Ring Imaging CHerenkov detector has been built as an upgrade of the Particle IDentification (PID) system of the hadron arm detection package of Hall-A at Jefferson Lab, where an electron accelerator in the "multi-GeV" region is dedicated to hadronic physics studies.

The accelerator configuration allows for three continuous beams, with energies up to 6 GeV, to be simultaneously delivered to three experimental halls equipped with complementary sets of detectors. Hall-A is dedicated to high luminosity and high resolution studies of inclusive and semi-inclusive electron scattering reactions. It is equipped with two identical, focusing magnetic High Resolution Spectrometers (HRS) [1] able to detect charged particles of momentum up to $4\,\mathrm{GeV}/c$. It is therefore well suited to perform scattering experiments with detection in final state of scattered electrons (in the HRS—electron arm) in coincidence with a particle knocked-out or produced from the target (protons, pions, kaons, ... in the HRS hadron arm). The characteristics of the Jefferson Lab electron beam facility, together with those of the experimental equipment, offer a unique opportunity to study hypernuclear spectroscopy via electromagnetically induced reactions. This new experimental approach is an alternative to the hadronically induced reactions studied so far.

Experiment E94-107 [2,3] has completed its first set of measurements, performing high-resolution hypernuclear spectroscopy by electro-production on carbon and beryllium targets. The reaction on carbon under study is $^{12}\mathrm{C}(e,e'\mathrm{K}^+)^{12}\mathrm{B}_\Lambda$, where the measurement in coincidence of the scattered electron e' with the produced kaon allows the measurement of the excitation energy spectrum of the produced Boron hypernucleus. On Beryllium, the reaction $^{9}\mathrm{Be}(e,e'\mathrm{K}^+)^{9}\mathrm{Li}_\Lambda$ measures the Lithium hypernucleus spectrum.

In order to obtain reasonable counting rates for the produced hypernuclear states, both the scattered electrons and the outgoing kaons must be detected at very small angles with respect to the beam ($\pm 6^\circ$). At so small angles, a very high background of pions and protons dominates over kaons. Hence, a powerful PID system is needed for unambiguous kaon identification with high π/p rejections.

The standard PID system in the hadron arm is composed by two aerogel threshold Cherenkov counters [4,1]. One has refractive index $n_1 = 1.015$ (AERO1) and the other has $n_2 = 1.055$ (AERO2). In both cases charged pions (protons) with momenta around $2\,\mathrm{GeV}/c$ are above (below) Cherenkov light emission threshold. Kaons emit Cherenkov light only in the detector with higher index of refraction (AERO2). Hence, a combination of the signals from the two counters can distinguish among these three species of hadrons: pions are selected by a coincidence of the two aerogel counters; protons by vetoing both counters; kaons by a signal in AERO2 and vetoing on AERO1. However, due to inefficiencies and delta ray production, the identification of kaons has a significant contamination from pions and protons which brings, in the case of the hypernuclear experiment, a very low signal-to-noise ratio in the interesting physics spectra. The requirement to increase this ratio by an unambiguous identification of kaons has driven the design of the RICH detector to be added to the two aerogel Cherenkov counters for improving the standard Hall A PID performance.

2. RICH detector layout

The Hall A RICH detector is conceptually identical to the ALICE HMPID design [5]. It uses a proximity focusing geometry (no mirrors involved), a CsI gaseous photocathode, and a 15 mm thick liquid perfluorohexane radiator [6]. Fig. 1 shows the working principle of the adopted solution. The Cherenkov photons, emitted along a conic surface in the radiator, are refracted by the perfluoro-hexane (C_6F_{14})-quartz-methane interface and strike a cathode plane segmented in small pads after traversing a proximity gap of 10 cm filled with pure methane. The photon detector is made of a Multi-Wire Proportional Chamber (MWPC), with one cathode formed by the pad planes allowing for the 2-dimensional localization of the photon hit. Three photocathode modules of

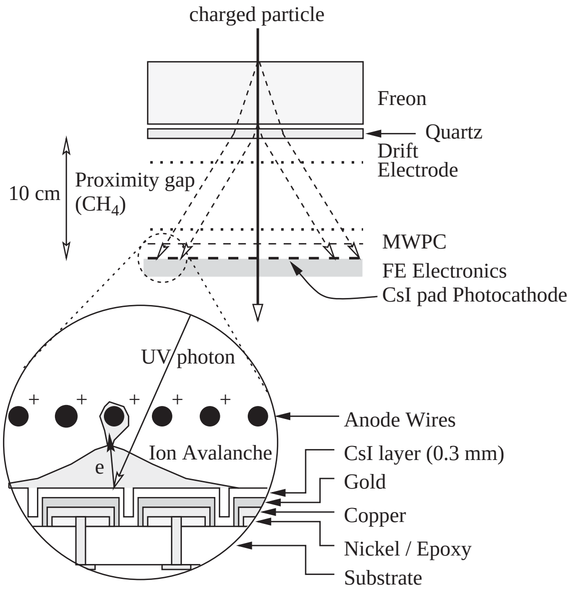

Fig. 1. Layout and working principle of the freon CsI proximity focusing RICH.

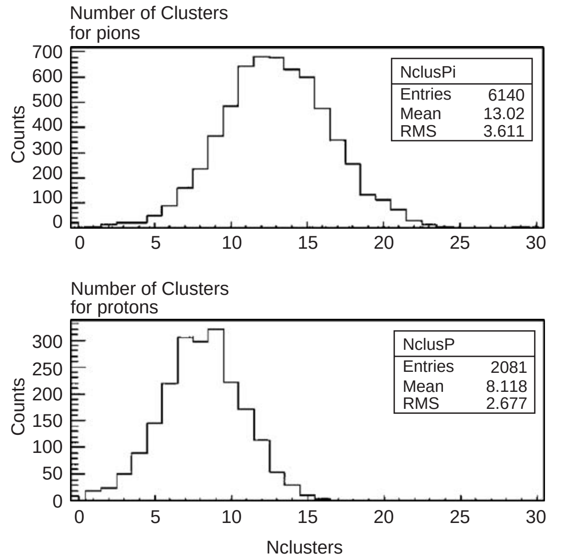

Fig. 2. Distributions of photoelectrons (pad clusters on the photocathode) for pions (top) and protons (bottom) of about $2\,\mathrm{GeV}/c$ momentum. Pion and protons are selected by the use of the two aerogel counters (see text in the introduction).

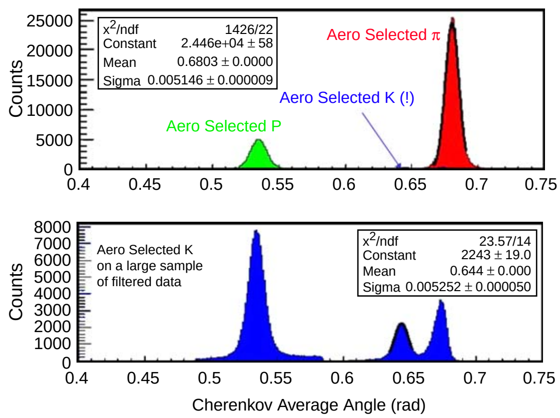

Fig. 3. Cherenkov angle distributions for protons ($\theta_{cher}{\sim}0.54\,\mathrm{rad}$), kaons ($\theta_{cher}{\sim}0.64\,\mathrm{rad}$) and pions ($\theta_{cher}{\sim}0.68\,\mathrm{rad}$). The aerogel particle selection has been used as explained in the text (see Introduction).

dimensions $640 \times 403\,\mathrm{mm}^2$ segmented in $8 \times 8.4\,\mathrm{mm}^2$ pads are assembled together for a total length of 1940 mm. The pad planes are covered by a thin (300 nm) substrate of CsI which acts as photon converter. The emitted photoelectron is accelerated by an electrostatic field between the pad plane (the cathode of the MWPC) and an anode wire plane at a distance of 2 mm from it. The induced charge on the pads is read out by a front-end electronics based on GASSIPLEX chips [5]. A total number of 11520 pad channels are read out by CAEN VME V550 Flash ADC modules [6].

3. Performance and results during the hypernuclear spectroscopy experiment

The RICH worked successfully during the experiment [3], where hadrons were detected in the momentum range $P^{\mathrm{hadr}} = 1.96 \pm 0.1\,\mathrm{GeV}/c$. In Figs. 2 and 3 the RICH key parameters are reported. The number of pad clusters produced by Cherenkov photons emitted by pions and protons (selected by aerogel counters as described in the Introduction) are shown in Fig. 2, top and bottom panels, respectively. The average number of photoelectrons detected for pions is $N^{\pi}_{\mathrm{p.e.}} = 13$, while for protons $N^{\mathrm{p}}_{\mathrm{p.e.}} = 8$, their ratio being in perfect agreement with the expected ratio of produced photons at $\sim 1.96\,\mathrm{GeV}/c$. In Fig. 3, the reconstructed Cherenkov angle distributions are reported. In the top panel the angular distributions have been obtained using samples of π^+, K^+ and p as selected by the two aerogel counters. The kaon selected sample is practically not visible due to the very high π/kaon ratio. For the dominant contribution of pions the obtained angle resolution is $\sigma_{\mathrm{Cher}} \simeq 5$ mrad, in agreement with Monte Carlo simulations [3]. The ''kaon'' contribution is shown in the bottom panel where a large sample of aerogel kaon selected events has been used. The reconstructed Cherenkov angle variable can be clearly used to get rid of the π and proton contamination. With a resolution of $\sigma_{\mathrm{Cher}} \simeq 5$ mr the separation between π and K^+ is about 6σ.

The performance reported here has been obtained with a measured quantum efficiency of about 25% at 160 nm [7] and at standard operating conditions with the MWPC operating at 2100 V. A MWPC gain of about 5×10^4 was estimated by fitting the charge amplitude signal Landau shape of the ionizing particle traveling through the photodetector and by the single photo-electron exponential pulse height distribution.

Fig. 4 shows the fundamental role of the RICH in identifying the kaons. In the left panel the spectrum of the time of coincidence between the triggers of the electron and hadron spectrometers is reported, as obtained by applying a selection for kaons using the two threshold aerogel counters. The kaon signal is barely visible while a significant contribution of mis-identified pions and protons clearly dominates the spectrum. The flat part of the spectrum is given by the random coincidences and the 2 ns structure is a reflection of the electron beam pulsed structure. The filled spectrum, exploded in the right panel, is obtained applying the RICH kaon selection. All contributions from pions and protons completely vanish.

In order to estimate the pion rejection factor a tight selection with aerogels has been used to

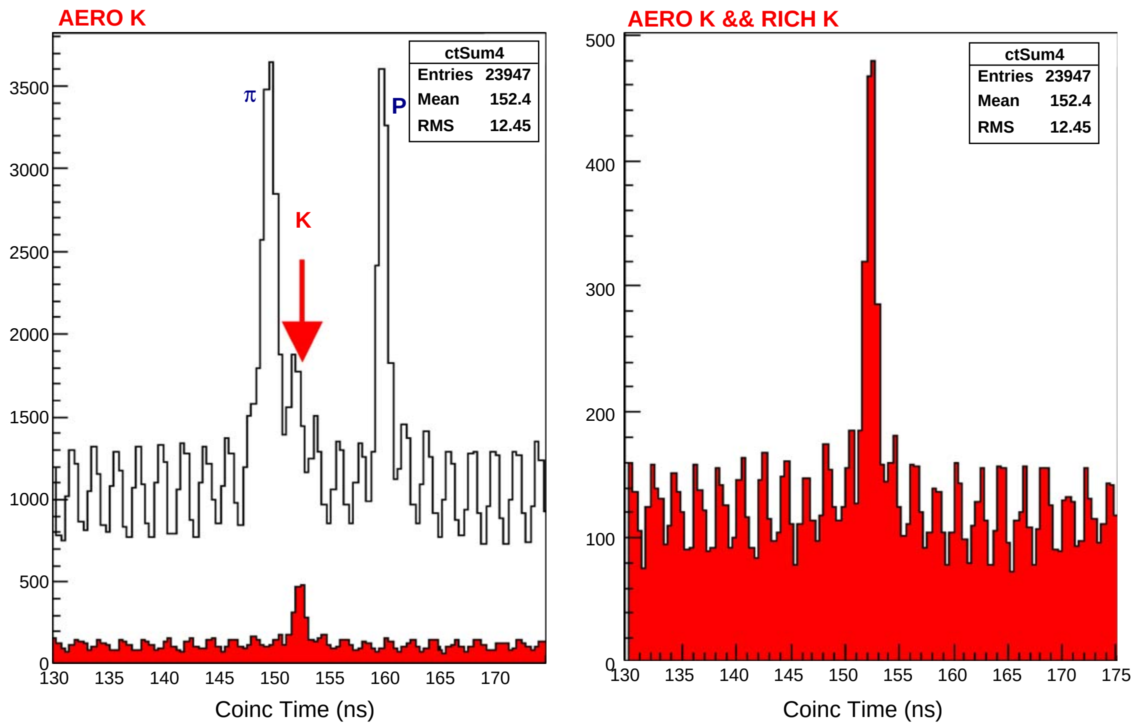

Fig. 4. Hadron arm vs. electron arm time of coincidence spectra. Left panel: empty histogram is obtained by selecting kaons only with the threshold Aerogel Cherenkov detectors. Filled histogram (expanded in the right panel) also includes the RICH kaon selection. The π/p contamination is clearly reduced to a negligible contribution.

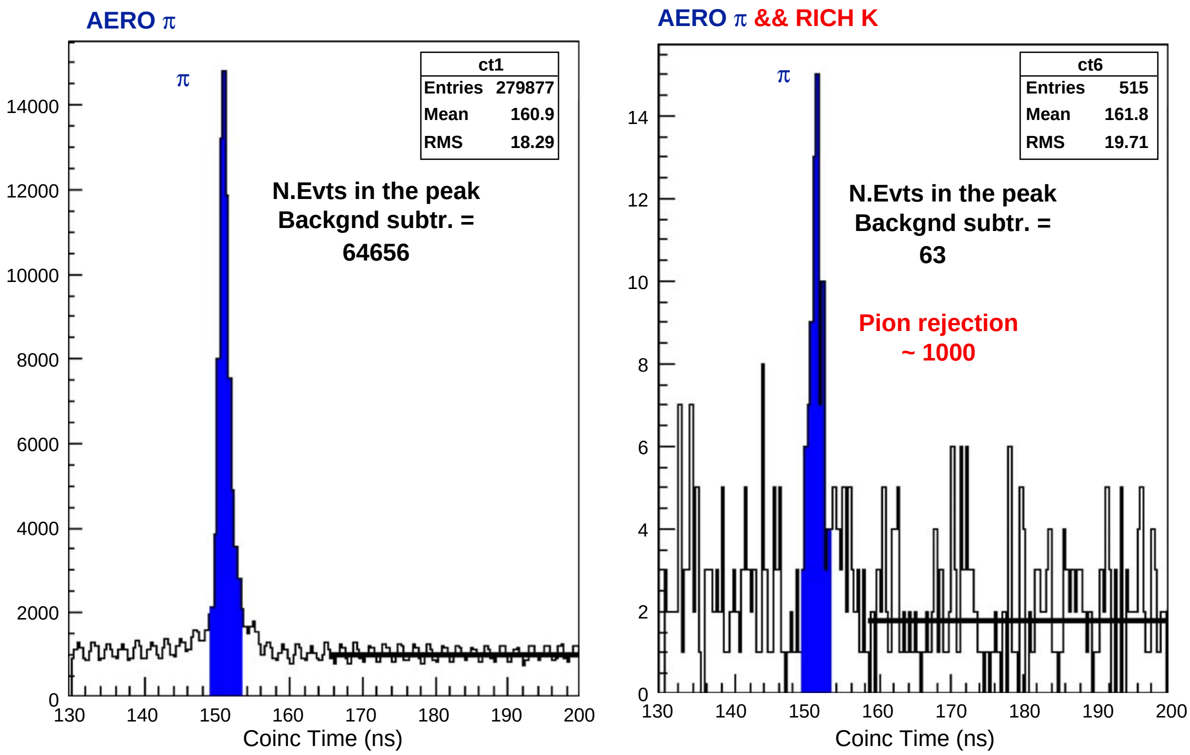

Fig. 5. In the left panel, the time of coincidence spectrum for pions selected by aerogel counters is shown. If a RICH KAON selection is applied the pion content is greatly reduced indicating a pion rejection ratio of ~1000 (right panel).

obtain a "pure" pion sample. In Fig. 5, the time of coincidence spectrum is reported for such a selected pion sample. In the right panel the additional RICH kaon selection has been applied. The RICH pion rejection factor can be estimated to be ~1000 from the pion peak content reduction factor.

As a preliminary physics result, showing the role of the RICH, the excitation energy of the boron hypernucleus produced in the reaction $^{12}C(e,e'K^{+})^{12}B_{\Lambda}$, has been reported in Fig. 6. Spectra are obtained with only aerogel kaon selection (top panel) and with the RICH kaon selection (bottom panel). Statistical significance of a hypernuclear level identification depends on the signal-to-noise ratio S/N defined as the total number of counts above background divided by the background statistical fluctuation, i.e. $S/\sqrt{(\mathrm{Bckgnd})}$. In the first case of Fig. 6 (only aerogel kaon selection) the levels at 2.6 MeV and at 6 MeV have $S/N{\sim}2.5$ each. This value cannot allow unambiguous assignment of a hypernucleus excitation level. With the addition of the RICH these levels can be assigned with S/N of ~8 and ~7, respectively. For beryllium and lithium targets, where the counting rate for hypernuclear production is less than that for carbon, the RICH kaon identification is expected to play a crucial role.

4. Summary and conclusions

A CsI RICH detector has been built and successfully operated during the Hypernuclear spectroscopy experiment at Jefferson Lab. It is a powerful tool for particle identification providing a clean kaon identification with a pion rejection ratio of ~1000. Average Cherenkov angle resolution $\sigma_{\theta_{\mathrm{Cher}}}{\sim}5$ mrad has been obtained for

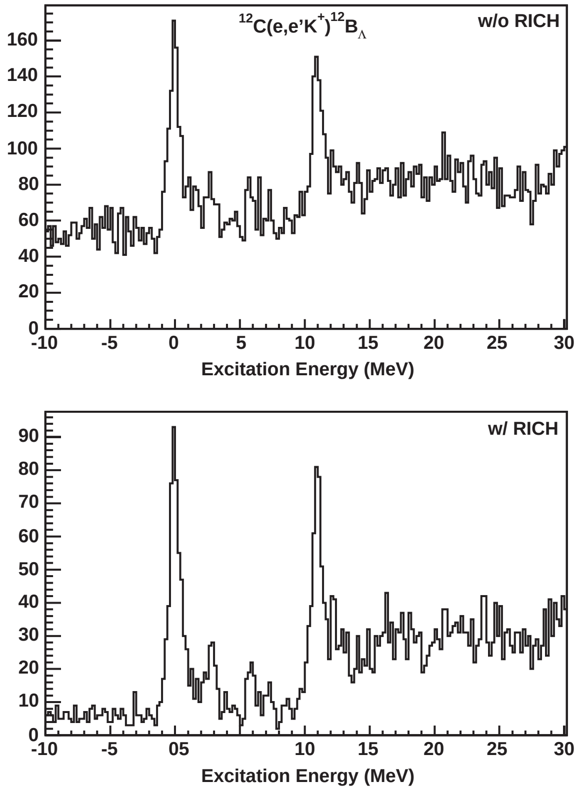

Fig. 6. $^{12}B_{\Lambda}$ excitation energy spectrum without and with the kaon RICH selection.

ultra-relativistic particles in good agreement with Monte Carlo simulations.

The impact of the RICH in the ongoing analysis has been shown. Upgrades are foreseen both to increase the maximum DAQ rate limit and to increase the maximum momentum for π/kaon separation.

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